THE MOVING-BOAT METHOD

INTRODUCTION

On large streams and estuaries the conventional methods of measuring discharge by current meter are frequently impractical and involve costly and tedious procedures. There may be no suitable facilities at remote sites. Where suitable facilities do exist, they may be inundated or inaccessible during floods. At some sites, unsteady flow conditions require that measurements be made as rapidly as possible. Measurements on tide-affected rivers must not only be made rapidly, but often continually, throughout a tidal cycle. The moving-boat technique is a method of rapidly measuring the discharge of large streams. It requires no fixed facilities, and it lends itself to the use of alternate sites if conditions make this desirable.

The moving-boat technique is similar to the conventional current-meter measurement in that both use the velocity-area approach in determining discharge. (See chapter 5.) In each method, a measurement is the summation of the products of the subsections of the stream cross section and their respective average velocities. Both techniques require that the following information be obtained:

1. Location of sampling verticals 1, 2, 3,. . .n across the stream in reference to the distance from an initial point.
2. Stream depth, d, at each observation vertical.
3. Stream velocity, V, perpendicular to the cross section at each observation vertical.

During a traverse of the boat across the stream, a sonic sounder records the profile of the cross section, and a continuously operating current meter senses the combined stream and boat velocities. A vertical vane alines itself in a direction parallel to the movement of water past it, and an angle indicator attached to the vane assembly indicates the angle between the direction of the vane and the true course of the boat. The data from these instruments provide the information necessary for computing the discharge for the cross section. Normally, data are collected at 30 to 40 observation points in the cross section for each run. Experience has shown that discharges determined by the moving-boat technique match, within 5 percent, discharges determined by conventional means.

The principal difference between the conventional measurement and the moving-boat measurement lies in the method of data collection. The standard current-meter method of measurement uses what might be called a static approach in its manner of sampling; that is, the data are collected at each observation point in the cross section while the observer is in a stationary position. This is in contrast to the dynamic approach to data collection utilized in the moving-boat method. Here, data are collected at each observation point while the observer is aboard a boat that is rapidly traversing the cross section.

THEORY OF THE MOVING-BOAT METHOD

The moving-boat measurement is made by traversing the stream along a preselected path that is normal to the streamflow. The traverse is made without stopping, and data are collected at intervals along the path. During a traverse of the cross section, the boat operator maintains course by "crabbing" into the direction of the flow sufficiently to remain on line (fig. 103). The velocity, V_b, of the boat with respect to the stream-bed along the selected cross-section path is the velocity at which the current meter is being pushed through the water by the boat. The force exerted on the current meter, then, is a combination of two forces acting simultaneously: one force resulting from the movement of the boat through the water along the cross-section path and the other a consequence of the natural streamflow normal to that path.

The velocity measurement taken at each of the sampling points in the cross section is a vector quantity that represents the relative velocity of water past the vane and meter. This velocity, V_V, is the vector sum of V, the component of stream velocity normal to the cross section at the sampling point, and V_b, the velocity of the boat with respect to the streambed along the selected path. The vector diagram in figure 104 depicts this relation.

The sampling data recorded at each observation point provide the necessary information to define V_V. The pulses-per-second reading from the rate-indicator unit is used in conjunction with a rating table to obtain the vector magnitude, V_V, while the angle reading, α, representing the angle the vane makes with the cross-section path, defines the direction of the vector.

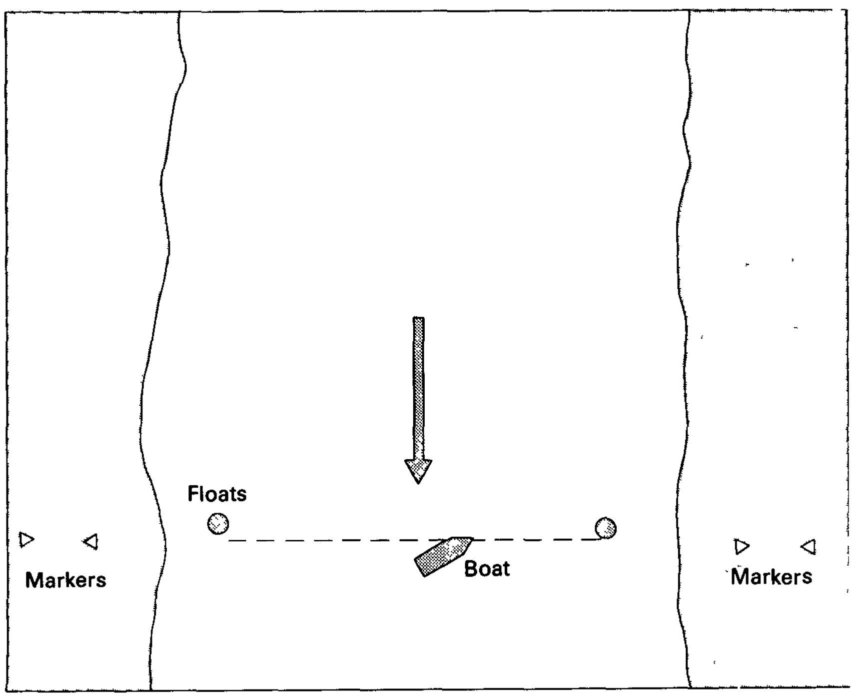


FIGURE 103.—Sketch of stream with markers.

Stream velocity, V, perpendicular to the boat path (true course) at each sampling point, 2, 3, 4, . . . $(n-1)$, can be determined from the relation

$$V = V_V \sin \alpha. \tag{17}$$

The solution of the above equation yields an answer which represents that component of the stream velocity that is perpendicular to the true course even though the direction of flow may not be perpendicular. This is the desired component.

From the same vector diagram, it can be seen that

$$L_b = \int V_V \cos \alpha \, dt, \tag{18}$$

where L_b is the distance that the boat has traveled along the true course between two consecutive observation points, provided the stream velocity is perpendicular to the path. Where the velocity is not perpendicular, an adjustment is required as explained on pages 207–208, where the adjustment of total width and area is discussed.

If one assumes that α is approximately uniform over the relatively short distance that makes up any one increment, then α may be treated as a constant. Therefore, equation 18 becomes

$$L_b \approx \cos \alpha \int V_V \, dt. \tag{19}$$

However,

$$\int V_V \, dt = L_V, \tag{20}$$

where L_V is the relative distance through the water between two consecutive observation points as represented by the output from the rate indicator and counter. Therefore,

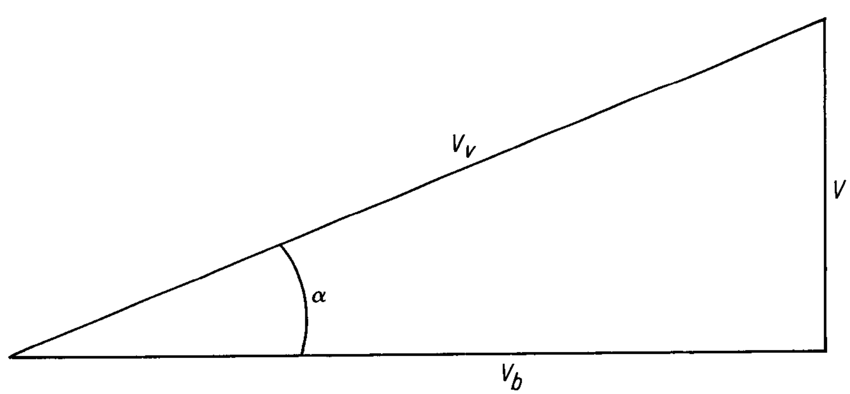


FIGURE 104.—Diagram of velocity vectors.

$$L_b \approx L_V \cos \alpha. \tag{21}$$

Finally, d, stream depth at each observation point, is obtained by adding the transducer depth to the depth obtained from the sonic-sounder chart. Upon determining V, L_b, and d for each vertical, the midsection method of computing a discharge measurement is used. (See p. 80–82.)

Much of the accuracy of a moving-boat discharge measurement depends upon the skill of the boat operator in maintaining a true course. Although even the most experienced pilot cannot be expected to keep the boat absolutely on course for an entire run, it is still extremely important that the measurement begin and end on line and that any deviations from the true course be kept as few in number and as small in magnitude as possible.

If velocity readings are taken while the boat is moving off course in an upstream direction, those readings will be greater than the true velocities; if the readings happen to be taken when the movement is toward the downstream direction, then the sampled velocity readings will be less than the true velocities. Thus, if one assumes the equal likelihood of overregistering or underregistering the stream velocities because of deviations from the true course, the errors can be considered compensating in nature. However, to further insure the reliability of the measurement, it is recommended that the results of at least six individual runs, each with from 30 to 40 observation points, be averaged to obtain the discharge when steady-flow conditions exist. This is practicable because of the ease and speed with which the extra runs can be made.

For unsteady-flow conditions on tidal streams, it will usually be desirable not to average the results from a series of runs but rather to keep them separate so as to better define the discharge cycle.

EQUIPMENT

Specialized instrumentation consisting of a sonic sounder, a vane with indicator, a special current meter with its associated electronic equipment, and an easily maneuverable small boat with some modifications, provide the capability needed for a moving-boat measurement.

VANE AND ANGLE INDICATOR

A vane with an indicating mechanism is mounted on the bow of the boat, with the vane centered approximately 3 to 4 ft (0.9 to 1.2 m) below the water surface (fig. 105). This assembly consists of a vertical, stainless-steel shaft with a pointer connected to its upper end and a thin vertical aluminum fin, 1-ft (0.3 m) high and 1½-ft (0.46m) long, attached to its lower end. The shaft is housed in an aluminum bearing tube and is mounted with ball bearings at the upper end and a teflon bearing (no lubrication needed) in the lower end of the tube so that the assembly (vane, shaft, pointer) is free to rotate as a unit. The vertical vane alines itself in a direction parallel to the movement of the water past it. The pointer is attached to the shaft so that it will be in line with the vane, pointing directly into the flow past the vane. The angle between the direction of the vane and the true course of the boat (the line of the cross section) is indicated on a dial by the pointer. The circular dial, calibrated in degrees on either side of an index point, swivels freely about the upper end of the vertical shaft, just below the pointer. A sighting device attached to the dial provides a means of alining the index point on the dial with the true course. In positive (downstream) streamflow the pointer above the dial will always point to the upstream side of the true course. Because the upstream side may be to the left or right side, depending on the direction in which the boat is traveling, and also because of possible negative velocities, the dial is calibrated in degrees (from 0 to 90) on both sides of its index point.

CURRENT METER

The current meter used by the U.S. Geological Survey is a component propeller type with a custom body made for mounting on the leading edge of the vane (fig. 105). The component propeller is less susceptible than are other types of meters to vertical components of velocity and was chosen to minimize errors created by the bobbing of the boat.

A 24-toothed gear passing in the proximity of a magnetic field is

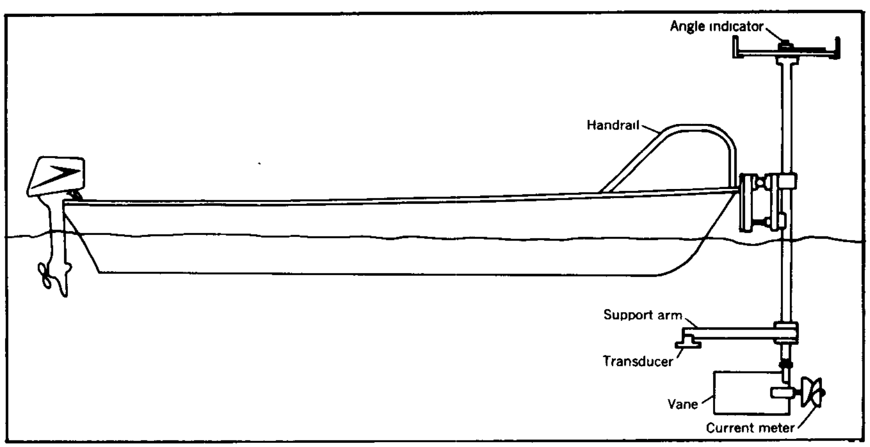


FIGURE 105.—Sketch of boat showing equipment.

used to generate 24 pulses per revolution of the propeller. The large number of pulses for each revolution facilitates the conversion of the pulse rate to an analog readout. An electronic pickup assembly registers these pulses and feeds them into a frequency-to-voltage converter, and they are then displayed as a reading on an electrical meter.

At one end of the meter cable is a metallic probe that is screwed into the meter body at the opening just behind the propeller nut (fig. 106). The probe is a permanent magnet that provides the magnetic field necessary for pulse generation. To function properly, the probe tip must be positioned within a few thousandths of an inch of the 24-toothed gear located within the meter. Adjustment of the probe position, which is seldom required, should be done with care to prevent damage to the probe tip.

Before the meter is used, the cup within the hub of the current-meter propeller should be filled with thin oil (Ott propeller oil) as shown in figure 106. The bearing assembly is then inserted into the hub, and the propeller nut is tightened. After the conclusion of a series of measurements, the cup should be emptied completely and cleaned before storage.

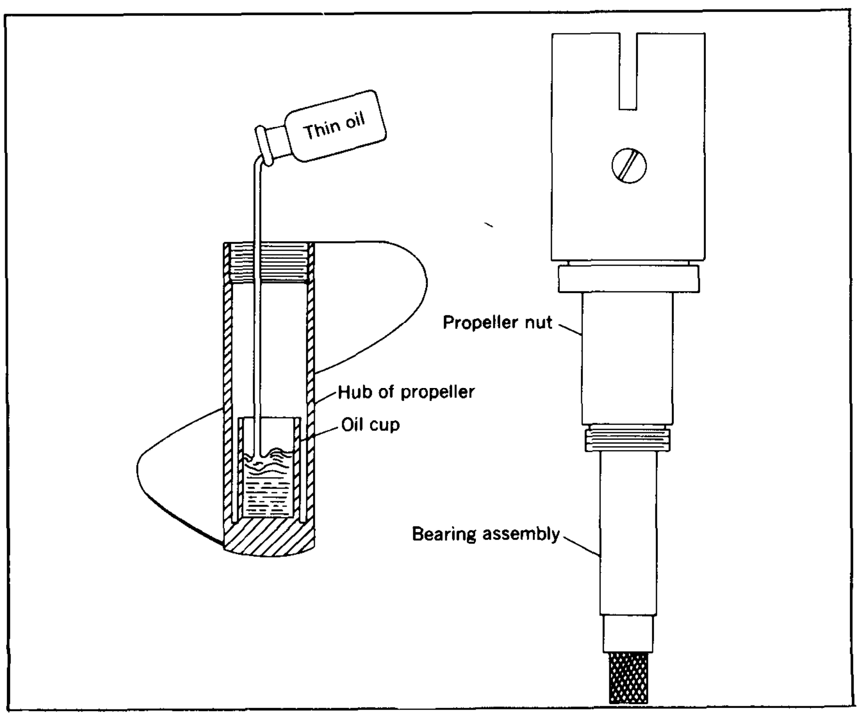


FIGURE 106.—Component propeller-type meter.

RATE INDICATOR AND COUNTER

One of the principal functions of the rate indicator and counter is to register the pulses received from the current meter, feed them into a frequency-to-voltage converter, and then display them as a reading on its electrical meter (fig. 107). These pulses are received through the current-meter cable which is plugged into the marked receptacle provided in the front panel of the unit. The current meter generating the pulses is calibrated so that the reading on the electrical meter in pulses per second can be converted to a particular velocity in feet per second through the use of a rating table (fig. 108). The value read from the electrical meter at any particular instant represents an instantaneous readout of velocity.

Two scale selections are available for the rate-indicator unit. If the switch is set at the "500" selection, the readout is taken from the lower scale of the panel meter; at the 1,000 setting, the upper scale is used. The 500 scale is the more sensitive of the two, and therefore its use is recommended during those measurements in which the velocity of the water past the meter is not great enough to give readings that exceed 500 pulses per second.

In addition to serving as a pulse-rate indicator from which velocity determinations can be made, this unit has also been designed to provide a method of automatically selecting measurement points in a section at regular intervals of travel distance. This design makes use of the fact that each revolution of the meter propeller generates 24

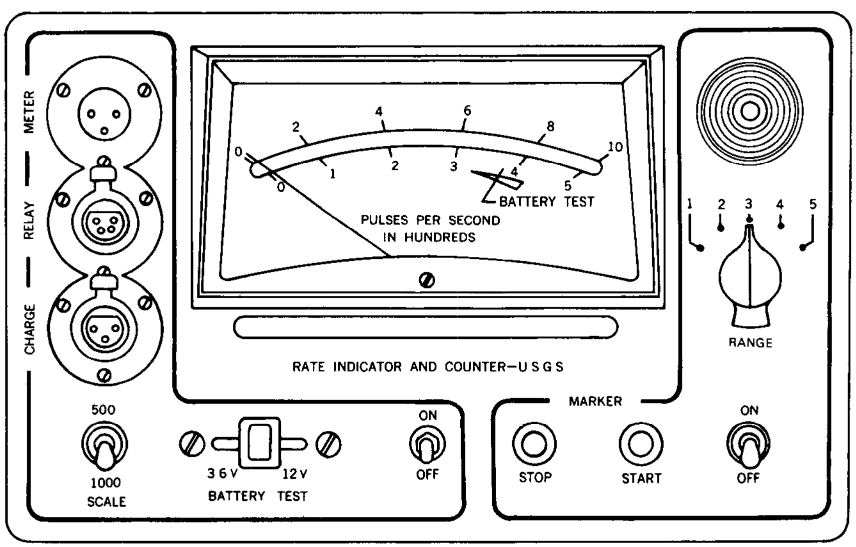


FIGURE 107.—Control panel of rate indicator and counter.

DEPARTMENT OF THE INTERIOR - GEOLOGICAL SURVEY
Water Resources Division
RATING TABLE FOR MOVING BOAT METER NO. . 2-4 . . . . . .
EQUATIONS: . V = 0.01768 N + 0.078 . . . . . . Limits of actual rating . . 1.0 . . to . . 10 . . . feet per second, Rated JULY 5, 1967.

Counts per Second	VELOCITY IN FEET PER SECOND																				Counts per Second
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	
0											0.96	1.05	1.14	1.23	1.32	1.40	1.49	1.58	1.67	1.76	0
100	1.85	1.93	2.02	2.11	2.20	2.29	2.38	2.46	2.55	2.64	2.73	2.82	2.91	3.00	3.08	3.17	3.26	3.35	3.44	3.53	100
200	3.61	3.70	3.79	3.88	3.97	4.06	4.14	4.23	4.32	4.41	4.50	4.59	4.67	4.76	4.85	4.94	5.03	5.12	5.21	5.29	200
300	5.38	5.47	5.56	5.65	5.74	5.82	5.91	6.00	6.09	6.18	6.27	6.35	6.44	6.53	6.62	6.71	6.80	6.88	6.97	7.06	300
400	7.15	7.24	7.33	7.42	7.50	7.59	7.68	7.77	7.86	7.95	8.03	8.12	8.21	8.30	8.39	8.48	8.56	8.65	8.74	8.83	400
500	8.92	9.01	9.09	9.18	9.27	9.36	9.45	9.54	9.63	9.71	9.80	9.89	9.98	10.07	10.16	10.24	10.33	10.42	10.51	10.60	500
600	10.69	10.77	10.86	10.95	11.04	11.13	11.22	11.30	11.39	11.48	11.57	11.66	11.75	11.84	11.92	12.01	12.10	12.19	12.28	12.37	600
700	12.45	12.54	12.63	12.72	12.81	12.90	12.98	13.07	13.16	13.25	13.34	13.43	13.51	13.60	13.69	13.78	13.87	13.96	14.05	14.13	700
800	14.22	14.31	14.40	14.49	14.58	14.66	14.75	14.84	14.93	15.02	15.11	15.19	15.28	15.37	15.46	15.55	15.64	15.72	15.81	15.90	800
900	15.99	16.08	16.17	16.26	16.34	16.43	16.52	16.61	16.70	16.79	16.87										900

TABLES OF L_b, IN FEET

Range No.	Angle α in degrees	0	1	2	3	4	5	6	7	8	9
1	0	18.2	18.2	18.2	18.2	18.2	18.2	18.1	18.1	18.1	18.0
	10	18.0	17.9	17.9	17.8	17.7	17.6	17.5	17.5	17.4	17.3
	20	17.1	17.0	16.9	16.8	16.7	16.5	16.4	16.3	16.1	16.0
	30	15.8	15.6	15.5	15.3	15.1	14.9	14.8	14.6	14.4	14.2
	40	14.0	13.8	13.6	13.3	13.1	12.9	12.6	12.4	12.2	11.9
2	0	36.5	36.5	36.5	36.5	36.4	36.4	36.3	36.2	36.1	36.1
	10	35.9	35.8	35.7	35.6	35.4	35.3	35.1	34.9	34.7	34.5
	20	34.3	34.1	33.8	33.6	33.3	33.1	32.8	32.5	32.2	31.9
	30	31.6	31.3	31.0	30.6	30.3	29.9	29.5	29.2	28.8	28.4
	40	28.0	27.5	27.1	26.7	26.3	25.8	25.4	24.9	24.4	23.9
3	0	73.0	73.0	73.0	72.9	72.8	72.7	72.6	72.5	72.3	72.1
	10	71.9	71.6	71.4	71.1	70.8	70.5	70.2	69.8	69.4	69.0
	20	68.6	68.2	67.7	67.2	66.7	66.2	65.6	65.0	64.4	63.8
	30	63.2	62.6	61.9	61.2	60.5	59.8	59.0	58.3	57.5	56.7
	40	55.9	55.1	54.2	53.4	52.5	51.6	50.7	49.8	48.8	47.9
4	0	146	146	146	146	146	145	145	145	145	144
	10	144	143	143	142	142	141	140	140	139	138
	20	137	136	135	134	133	132	131	130	129	128
	30	126	125	124	122	121	120	118	117	115	114
	40	112	110	108	107	105	103	101	99.6	97.7	95.8
5	0	292	292	292	292	291	291	290	290	289	288
	10	288	287	286	284	283	282	281	279	278	276
	20	274	273	271	269	267	265	262	260	258	255
	30	253	250	248	245	242	239	236	233	230	227
	40	224	220	217	214	210	206	203	199	195	192

SIN of ANGLE α

Angle α	0	1	2	3	4	5	6	7	8	9
0	.000	.017	.035	.052	.070	.087	.105	.122	.139	.156
10	.174	.191	.208	.225	.242	.259	.276	.292	.309	.326
20	.342	.358	.375	.391	.407	.423	.438	.454	.469	.485
30	.500	.515	.530	.545	.559	.574	.588	.602	.616	.629
40	.643	.656	.669	.682	.695	.707	.719	.731	.743	.755
50	.766	.777	.788	.799	.809	.819	.829	.839	.848	.857

FIGURE 108.—Sample tables of meter rating, L_b, and sine α.

evenly spaced pulses, and that from the calibration of the meter it can be determined that one pulse is equal to some fraction of a foot of meter travel through the water, or of water travel past the meter. By using a set of frequency-dividing modules, provision is made for these pulses to be electronically counted to a preset number, at which time an audible signal is generated and the sounder chart is automatically marked. The counter then automatically resets itself, and the process is repeated. The purpose of the audible signal is to let the boat crew know when a sampling location is reached. At this point they will take an angle reading from the pointer and a readout from the electrical meter. The markings on the sounder chart are automatically triggered by an electrical impulse transmitted to the depth-sounder unit by a relay in the meter electronics. The relay cable from the counter to the sounder should be plugged into the appropriately marked receptacle on the front panel of both units. The markings on the sounder chart locate observation points in the cross section and thus show where depth readings should be taken.

Preset intervals that are available on each unit are as follows:

Range selection	*Pulse counts*	*Distance, in feet*
1	1,024	18.75
2	2,048	37.5
3	4,096	75
4	8,192	150
5	16,384	300

The distances listed above are typical; exact ones depend upon the calibration of the particular current meter used. If possible, the pulse-selector switch should be set for a distance that will divide the measured width between the two floats into from 30 to 40 increments. For example, if the distance between floats is 500 ft (150 m), range 1 should be selected; for a distance of 1,000 ft (300 m), range 2 should be used, and so on. Each distance listed in the table above represents L_V, the relative distance through the water, and it will be somewhat larger than the corresponding L_b value, the distance along the true course that the boat has traveled. L_b is the distance one should use to determine the number of observation points that will be taken in a given cross section. However, the listed L_V values can be used to estimate roughly the number of observation points—the estimated number will always be less than the actual number of observation points.

The rate indicator and counter has two internal power supply packs, each consisting of a set of nickel-cadmium rechargeable batteries. A battery test switch located on the front panel of the unit can be used to test the condition of either the 3.6-volt or the 12-volt power supply (fig. 107). Testing should be done with both the main power and the marker switches off. A reading of the panel meter above the test switch will indicate the degree of charge. A needle deflection greater than the battery testline mark indicates a satisfactory charge level for most measurement requirements. A fully charged battery pack will operate satisfactorily from 12 to 16 hr. A marginal reading, with needle deflection just to the test mark, indicates approximately 4 to 8 hr of useful battery operation remaining. A reading below the mark serves as a warning that a battery charge is needed.

BATTERY CHARGER

The battery charger serves as a dual unit for charging either one of the two battery supply packs located within the rate indicator and counter unit. Its charge plug is inserted into the charge receptacle located on the panel of the rate indicator and counter. The other plug should be connected to a 115-volt, 60-cycle line power supply. With proper care the batteries should provide many years of service.

SONIC SOUNDER

A portable sonic sounder (fig. 109) is used to provide a continuous strip-chart record of the depth of the stream, that is, a profile of the cross section between the two floats. Its transducer releases bursts of ultrasonic energy at fixed intervals. The instrument measures the time required for these pulses of energy to travel to the streambed, to be reflected, and to return to the transducer. With a known propagation velocity of sound in water, the sounder computes and records the depth. Accuracy of the recording depth sounder is approximately ±0.5 ft (0.15 m). The sounder used in this application is a commercially available model with a minor modification for automatically marking the chart at each observation point in response to an electrical pulse from the meter electronics. The sounder is powered by a standard lead-acid battery of 6 or 12 volts, depending on the model of the sounder.

One minor modification to the sonic sounder is the installation of a receptacle on its front panel into which is plugged the relay cable from the rate indicator and counter. The purpose of this relay connection is to transmit the electrical pulses from the counter unit that will automatically trigger the vertical-line markings on the sounder chart. This provision for automatically marking the sounder chart at regular intervals of distance traveled eliminates the need for the manually operated "mark" switch, except in the event that the relay cable is damaged or missing. Then, as an expedient measure, the chart is marked at each observation point by manually pulling the switch at each tone signal sounded by the counter unit.

Three paper-feed speeds are provided with the unit. The small lever in the lower left-hand corner of the recorder chassis is the control. The set of speeds available will vary according to the model. Some models

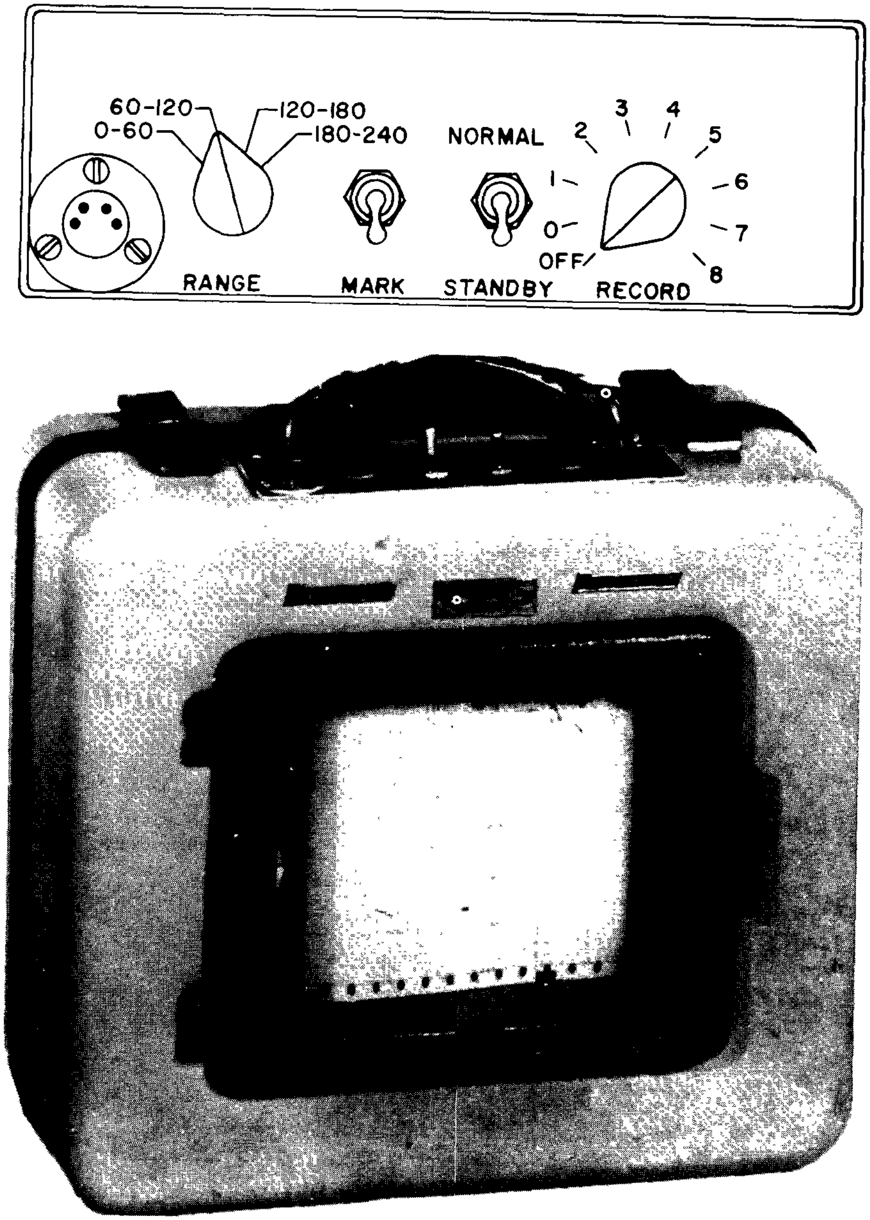


FIGURE 109.—Sonic sounder and control panel.

provide choices of 12, 30, and 60 in/hr (0.30, 0.76, and 1.52 m/hr), and others 36, 90, and 180 in/hr (0.91, 2.29, and 4.57 m/hr). A suitable chart speed is one that results in a spacing of approximately 0.25 in between the vertical-line markings that are set on the chart during the measurement. Spacing wider than that needlessly wastes chart paper, whereas much narrower spacing results in poor resolution of the streambed trace. Narrow spacing also causes difficulty in determining the fractional part of a full spacing that should be assigned to the final width increment. Width of spacing is dependent upon the range setting on the counter unit, the current-meter velocity, and the chart speed. Table 12, computed for a current-meter velocity of 5 ft/s (1.52m/s), provides an example of typical spacing distances expected for various combinations of chart speed and range distance.

BOAT

Any easily maneuverable small boat that is sufficiently stable for the stream on which it is to be used is adequate for a moving-boat measurement. A photograph of a boat with the vane assembly mounted is shown in figure 110.

Preparation of the boat.—A 12×12×¼-in steel plate should be so attached that it is centered on the bow of the boat, perpendicular to the centerline of the boat, and as nearly vertical as possible. This plate must be securely anchored because at high velocities great force will be exerted on it. It may be necessary, depending on the style of boat being used, to erect handrails on the forward part of the boat, similar to those shown in figure 105. This is done for the safety of the angle reader who must stand in the bow.

Mounting of the equipment.—The 12×12-in aluminum plate on the vane assembly is attached to the 12×12-in steel plate on the bow of the boat. It is necessary to clamp these two plates together and drill four holes for accepting bolts to permanently fasten the plates together. The general location of the bolt holes should be near the four corners, but exact placement is not critical.

The two cap screws in the depth adjustment clamp that hold the aluminum bearing tube of the assembly (fig. 111) can be loosened so

TABLE 12.—*Spacing of vertical-line markings, in inches, on the sonic-sounder chart for various combinations of chart speed and range distance*

[Computed for a current-meter velocity of 5 ft/s.]

Chart speed	Range distance				
	18 75 ft	37.5 ft	75 ft	150 ft	300 ft
36 in/hr	0.04	0.08	0.16	0.32	0.64
90 in/hr	.10	.20	.40	.80	1.6
180 in/hr	.20	.40	.80	1.6	3.2

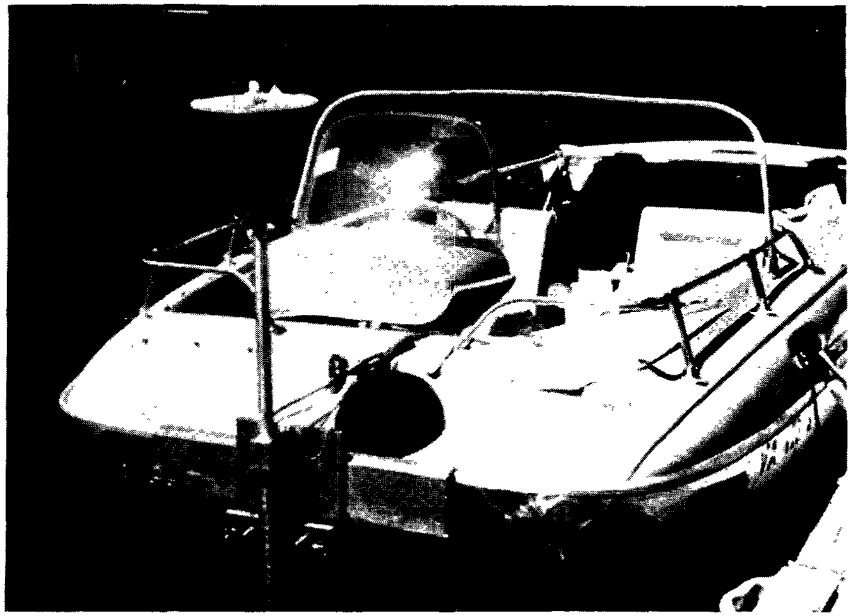


FIGURE 110.—Boat with mounted vane assembly.

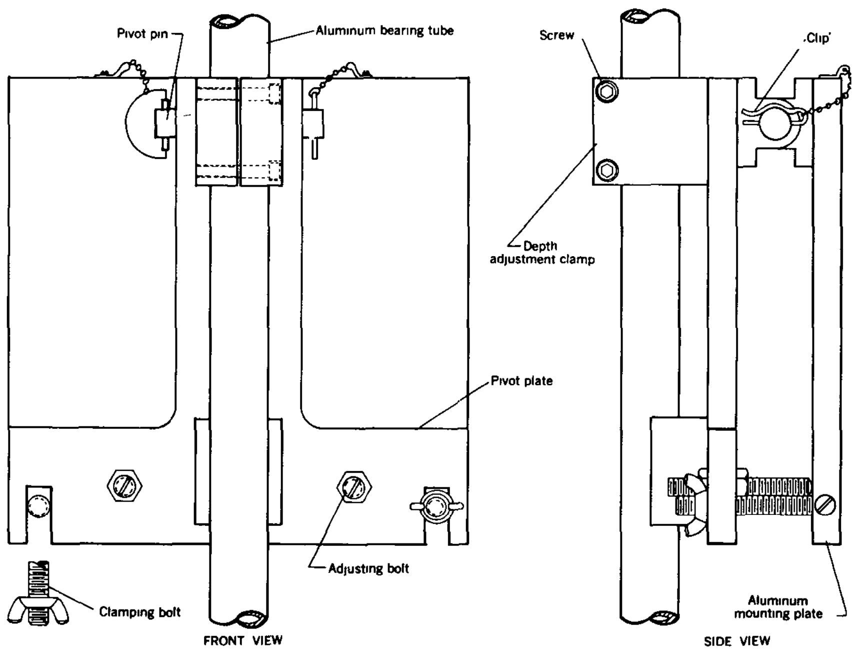


FIGURE 111.—Detailed view of vane-mounting assembly.

that the tube may be either raised or lowered in order to position the meter at the desired depth. This depth should preferably be at least 3 ft (0.91 m) to avoid the effect of surface disturbances and not greater than 4 ft (1.22 m) to avoid the danger of too great a torque being exerted at high velocities. Caution should be exercised to avoid high boat speeds, for the drag on the vane assembly is proportional to the square of the velocity of the water past the vane and therefore increases very rapidly with speed.

The sonic-sounder transducer is mounted on a support arm at a depth of either 2 or 3 ft (0.61 or 0.91m). It can be positioned by first loosening the two cap screws that secure the support arm to the aluminum bearing tube of the vane assembly and then moving the arm either up or down to the desired depth.

Because the vane assembly is mounted perpendicular to the centerline of the boat, it will change slightly from its original vertical position as a result of the raising of the bow of the boat during the moving-boat measurement. To offset this change and thus allow for vertical positioning of the assembly during normal boat operation, the mounting assembly provides for a compensating angle adjustment to be accomplished through the use of two adjusting bolts and a pivot plate (fig. 111). By screwing these bolts either inward or outward, the lower portion of the assembly can be pivoted toward or away from the boat. If the adjusting bolts are touching the aluminum plate when the assembly is in a vertical position, they must be screwed away from the plate so that the lower portion of the assembly can then be pivoted toward the boat and secured in position by use of two clamping bolts. The degree of adjustment would depend upon the operating velocity of the boat during the measurement.

Removal of the equipment.—After the measurements are completed, the vane assembly can be removed while leaving the aluminum plate bolted to the steel plate on the bow of the boat. This is accomplished by first loosening the wing nuts on the two clamping bolts of the plate and then removing the clip and sliding out the pivot pin that secures the assembly to the aluminum plate (fig. 111). Prior to doing this, the meter and the transducer cables should be disconnected from the rate indicator and the sonic sounder, respectively.

MEASUREMENT PROCEDURES

Procedures for a moving-boat measurement include selection and preparation of a suitable measuring site, preparation and assembly of the equipment used for the measurement, and a selection of settings for the instruments used to collect the data.

SELECTION AND PREPARATION OF THE MEASUREMENT SITE

Some preparation is required at the site prior to starting a series of moving-boat measurements. First, a path for the boat to travel is selected, it being as nearly perpendicular to the flow direction as possible. Then, two clearly visible range markers are placed on each bank in line with this path. The color of these markers should contrast sharply with the background. Spacing between the markers is dependent upon the length of the path, the longer paths requiring greater spacing. Approximately 100 ft (30 m) of spacing is needed for each 1,000 ft (300 m) of path length. Next, anchored floats are placed in the stream 40 to 50 ft (12 to 15 m) from each shore along the selected path (fig. 103). In making a traverse, this distance is needed for maneuvering the boat when entering or leaving the path. The floats should be placed so that the depth of water in their vicinity is always greater than 3 to 4 ft (0.9 to 1.2 m), which is vane depth. Large plastic bleach containers are suitable for use as floats; styrofoam cubes can also be used. It is preferable not to place the floats directly in the boat path but rather 10 to 20 ft (3 to 6 m) upstream. Their purpose is to mark the beginning and ending points of the boat measurement, and by offsetting them upstream they can serve that purpose without being in the way as the boat approaches along the selected path. Finally, the width of the stream is measured by triangulation, stadia, or other methods, and the exact locations of the floats are determined. Because the floats are close to the bank, a tape measure can be used to determine the distance from edge of water to each float. These distances should be recorded in the spaces provided on the front page of the discharge-measurement notes, for they will be used in the computation of the measurement.

If a station is to serve as a site for moving-boat discharge measurements on a continuing basis, it will probably be desirable to construct permanent range markers. Such markers would serve two useful purposes. First, determination of stream width would become a relatively simple procedure because of the availability of the constant distance between the markers once this distance has been established. A tape measure could be used to obtain the horizontal distance from the nearest marker to the water's edge on each bank. Subtracting these two distances from the established distance between the two streamward markers would provide the width of the stream. A second advantage would be that if the need arose, the markers could serve as permanent initial points from which cross-section profiles of the measurement section could be constructed.

PREPARATION OF THE EQUIPMENT

The special equipment and instruments necessary for a moving-boat measurement have been described in some detail on pages 187–197 under the general heading "Equipment." The purpose of this section of the manual is to summarize, for the convenience of the boat crew, the steps involved in the assembly of the equipment and in the selection of the instrument settings.

ASSEMBLY OF THE EQUIPMENT

The steps listed below should be followed in assembling the equipment:

1. Permanently mount a steel plate to the bow of the boat (p. 195) and then attach the aluminum plate of the vane assembly to it (p. 197). Both of these steps are "one time" operations that should be completed in advance of the trip.
2. Several days prior to the trip, check the batteries in the rate-indicator and counter unit and the storage battery for the sonic sounder to see that they are adequately charged. This will provide time to charge the batteries, if necessary, before the start of the trip.
3. Attach the sonic-sounder transducer to its support arm on the vane assembly (fig. 105).
4. Attach the current meter to the leading edge of the vane (fig. 105).
5. Use the pivot pin and clip and the two clamping bolts of the aluminum plate to secure the vane assembly to the plate (fig. 111).
6. Position the current meter at the desired depth (3 to 4 ft). This is done by loosening the two cap screws in the depth adjustment clamp and then raising or lowering the aluminum bearing tube to the proper position before retightening the screws. Measure the meter depth and record it in the measurement notes once positioning is completed.
7. Route the current-meter cable up the vane assembly and plug it into the marked receptacle on the rate indicator and counter unit. To prevent entanglement, the cable should be taped to the aluminum bearing tube in several places. It is necessary to provide some slack in the cable at its lower end to allow for the movement of the meter as the vane rotates during the measurement.
8. Position the sonic-sounder transducer at a depth of 2 or 3 ft. This is accomplished by first loosening the two cap screws that secure the support arm to the aluminum tube and then sliding the arm either up or down the tube to the proper position before tightening the screws. Measure the transducer depth and record it in the measurement notes at this time.
9. Route the transducer cable up the vane assembly, securing it by tape to the aluminum bearing tube; feed it through the hole

provided near the hinge of the sonic-sounder case; and then plug it into the marked receptacle at the back of the dividing plate.

10. Insert the battery cable of the sonic sounder into the marked receptacle at the back of the dividing plate of the unit. It can be fed through one of the holes provided near the hinge. A standard 6- or 12-volt storage battery, depending on the sonic-sounder model used, should be used as a power supply (p. 193).
11. Plug the relay cable from the counter unit to the sonic sounder into the marked receptacle on the front of each unit.
12. Use the two adjusting screws (fig. 111) to provide for the compensating angle adjustment of the vane assembly as described on page 197.

SELECTION OF THE INSTRUMENT SETTINGS

The notekeeper is responsible for the functioning of the rate indicator and counter and the recording depth sounder. To assure proper operation of the equipment, it is necessary that he make several preliminary instrument settings for each unit prior to the measurement. The following is a list of the steps involved in obtaining these settings:

Sonic sounder:

1. Check to see that the pulleys turn smoothly and that the stylus enters the track easily.
2. Set the operation switch to "stand by" position.
3. Turn on the unit by rotating the "record" switch clockwise to some low-numbered position and wait a few minutes for the tubes to warm up.
4. Set the depth-range selection at phase 1 (0–60 ft) and advance the gain control to obtain the "zero mark" near the top of the sounder chart.
5. Set the "zero mark" on the zero line of the recorder paper through use of the zero adjustment screw located behind the top pulley.
6. Continue to advance the gain until the "echo mark" appears somewhere below the "zero mark." If no echo appears when the gain is opened, switch the range control to the next phase (60–120 ft) and so on until the bottom is found.
7. Determine the optimum chart speed through use of table 12; then use the small lever in the lower left-hand corner of the recorder chassis to make this selection.
8. Change the operating switch from "stand by" to "normal" position several minutes before the measurement begins. This will start

the chart recording and provide an opportunity for a final check of instrument operation before the measurement begins.

Rate indicator and counter:

1. Select the desired scale for the rate-indicator meter located on the panel.
2. Check both battery packs with the battery test switch. This final check will have been preceded by a test several days before the measurement date in order to provide time to charge the batteries if needed (p. 199).
3. Set the rate-indicator switch to "on" position.
4. Set the marker switch to "on" position. (The actual marking will not begin until the "start" button is depressed.)
5. Select a range setting that will provide between 30 to 40 observation points. Because of the scale settings available, this may not always be possible, in which case choose that comprise setting that will come closest to meeting this provision.

After all the control settings are completed, the instruments are ready for use. The "start" and "stop" buttons on the panel of the counter unit are used to begin and end instrument operation at the precise moments the bow of the boat reaches the first and second floats, respectively. The operation of these button controls in regard to the starting and stopping procedure is described in the section of the manual that immediately follows.

FUNCTION OF THE CREW MEMBERS

Three crew members are necessary for making a moving-boat discharge measurement. They include a boat operator, an angle observer, and a notekeeper. Before crew members begin making discharge measurements by the moving-boat method, it is important that they develop a high degree of proficiency in all phases of the technique. This can be done by making practice measurements at a site where the discharge is known and then comparing the moving-boat discharge with the rated discharge. If there is no suitable site available for that purpose, the boat crew should make a series of moving-boat measurements at a single location and compare results for repeatability.

BOAT OPERATOR

Before the measurement begins, the boat operator should become thoroughly familiar with the sampling site. In tidal streams the operator should be familiar with conditions during all phases of the tidal cycle. This will help him avoid running the boat aground in shallow depths and damaging the submerged equipment. While maneuvering the boat, it is necessary to avoid sudden sharp turns that might result in damage to the meter cable by causing it to be wrapped around the vane assembly.

The operator should select an approach path for the boat that will allow it to be properly maneuvered into position prior to passing the first float. The path should begin from a downstream position as close to the riverbank as depth considerations permit. From such a starting point the boat can be accelerated to near its normal operating speed and the turn into the measuring section can be completed before the measurement begins. By attaining both the proper speed and alinement prior to reaching the float, the instrument readings will have time to stabilize before the initial sample is taken.

During a traverse the only function of the boat operator is to pilot the boat. He maintains course by "crabbing" into the direction of flow sufficiently to remain on line throughout the run. As varying stream velocities are encountered in the cross section, he should rely more upon steering adjustments to keep the proper alinement than upon acceleration or deceleration of the boat. Alinement is determined by sighting on the shore which is being approached. Much of the accuracy of the measurement depends on the skill of the boat operator in maintaining a true course with the boat.

Because the stream velocity is calculated as a sine function of angle alpha (fig. 104, eq. 17), small angles should be avoided whenever possible. It is desirable to maintain angle alpha at approximately 45°. The reason for this is that an error of several degrees in reading angle alpha would be more significant at small angle readings than the same error at larger angle readings. In order to maintain an angle of 45°, the velocity of the boat must be equal to that of the stream. This can be done if the stream velocity is greater than 2.5 ft/s (0.75 m/s); however, control of the boat is difficult to maintain below that velocity. For example, in tidal streams the stream velocity will often vary from 0 to several feet per second; therefore, it is not always possible to maintain an angle as large as 45°, and the measurement must be made using smaller angles.

ANGLE OBSERVER

A second man alines the dial of the vane indicator through its sighting device and, upon receiving the audible signal from the pulse counter, he reads the angle formed by the vane with respect to the true course. He reports the angle to the notekeeper who then records it. If the boat has strayed from the true path, the angle reader should sight parallel to the cross-section markers rather than at the markers themselves.

NOTEKEEPER

The notekeeper has several functions to perform. Prior to the measurement it is his responsibility to see that the preparation of all equipment pertaining to the rate indicator and counter and to the sonic sounder is completed satisfactorily. That includes not only equipment assembly but also selection of appropriate instrument settings.

The accuracy of the sonic sounder varies with changes in the velocity of sound in water, which in turn varies slightly with temperature, dissolved solids, and other variables. Thus sounder output should be compared to a known depth. Any significant error detected in the comparison can be expressed as a percentage of the known depth, and this percentage would be applicable to all depths determined by the sonic sounder. Consequently, this percentage correction should be applied to the total area and total discharge.

A check to determine that the current meter and rate indicator are functioning properly is also desirable. Such a check can be made by comparing the indicated velocity to a velocity determined by the Price current meter. This test is intended to determine proper operation only and is not intended for calibration purposes.

It is the notekeeper's responsibility to operate the controls provided on the equipment for starting and stopping the counter. It is important to the accuracy of the measurement that this unit promptly begin and end its operation at the first and second floats, respectively. This is accomplished by operating the "start" and "stop" buttons on the panel of the counter in the following manner:

1. Approximately 1 s before the boat reaches the first float, the "start" button is depressed; then it is released at the moment of passing. This marks the sounder chart, resets the counter, and starts it.

Marking of the sounder chart and sounding of the beeper (tone signal) will be automatic during the measurement. This will occur at regular intervals as determined by the setting of the range switch on the panel of the counter unit.

2. At the moment the bow of the boat reaches the second float, the "stop" button is depressed for 1 s and then released. This marks the sounder chart, signifying the end of the measurement, and stops the counter.

During the measurement the notekeeper records the angle reading at each signal as it is called out by the angle reader. He also reads and records the instantaneous "velocity" from the rate indicator meter at the same time. Readings are taken at all observation points as defined by the tone signals, including the two float positions.

If the time between consecutive measurements is short, it is desirable to leave the operating switch of the sonic sounder in the "normal" position until the measurement series is concluded. In this way the chart continues to advance between measurements, but there are no vertical line markings. This absence of vertical lines provides a gap on the chart that clearly sets off one measurement from another.

COMPUTATION OF THE DISCHARGE MEASUREMENT

COMPUTATION OF UNADJUSTED DISCHARGE

The method of computing discharge measured by the moving-boat technique is basically similar to the computation method used for conventional current-meter discharge measurements. (See p. 80–82). The discharge in a subsection, q, is the product of the subsection area of the stream cross section and the average velocity in the subsection. The midsection method of computation is used in which it is assumed that the average velocity at the observation vertical is the average velocity for a rectangular subsection. The rectangular subsection extends laterally from half the distance from the preceding observation vertical to half the distance to the following observation vertical and extends vertically from the water surface to the sounded depth (fig. 112). The summation of the discharges of the subsections, $q_1, q_2, q_3, \ldots q_n$, is the total unadjusted discharge of the stream. A step-by-step outline of the computation procedure, which refers to the sample measurement notes shown in figure 113, is given here as a guide to the hydrographer who computes the discharge from the field observations.

1. The data in the first column of figure 113 are the angle readings recorded by the notekeeper during the measurement. Because these readings begin and end at the float positions (there are no edge-of-water readings), they represent the values observed at locations 2, 3, 4, . . . $(n-1)$.

2. Each value in column 2 represents an incremental distance the boat has traveled along the cross-section path between two consecutive observation points. For example, α_x (col. 1) represents the angle reading at location x, and L_{b_x} (col. 2) is the incremental distance the boat has traveled along the true course, extending from the previous observation point, $x-1$, to the location x where the reading was taken.

The values in column 2 can be read directly from a table (fig. 108) by using the angle values recorded in column 1 and the range number as determined by the range selection on the counter unit. Two exceptions are the first and last values in the column, representing the distance to each float from its nearest edge of water. They are determined by direct measurement prior to the actual run. This is necessary because the actual boat run does not begin and end at the edge-of-water positions and thus is not set up to measure those distances. Therefore, the beginning angle reading, α_2, at the first float is not used for obtaining distance from the edge of water to that float. It should also be noted that L_{b_3} is always recorded as one-half of the value found in the table. This is necessary because the counter unit has been programed to signal at a "half-count" on its first count routine. All remaining values can be recorded directly from the table of L_b values, without any changes, with the possible exception of the one determined from the last angle reading which was made at the second float. This angle reading may or may not have been made at

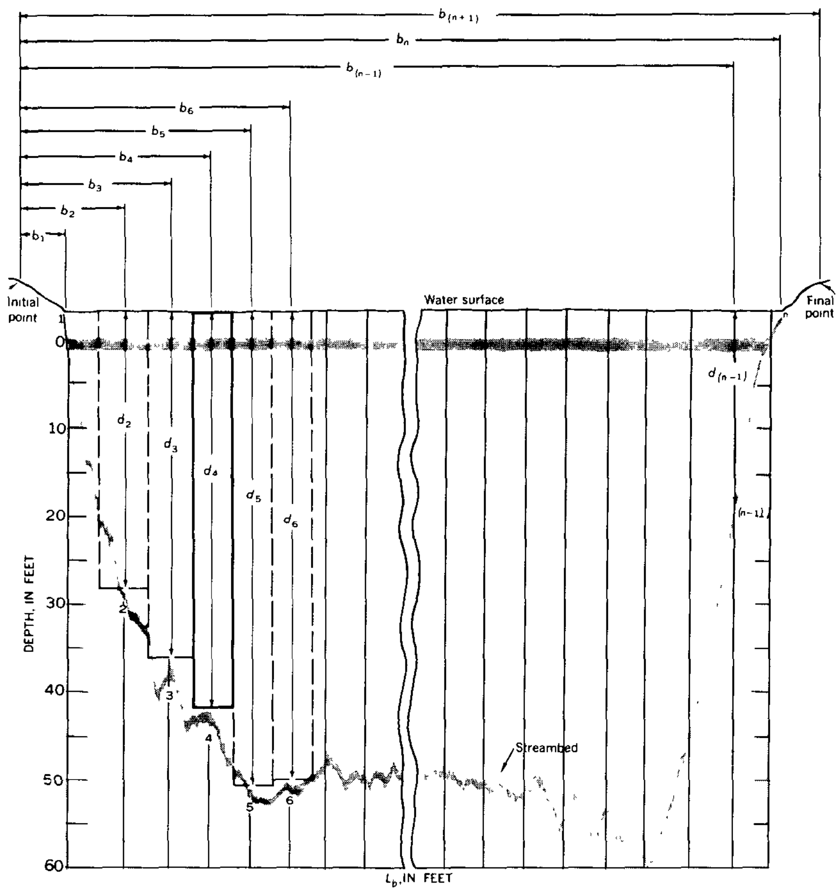
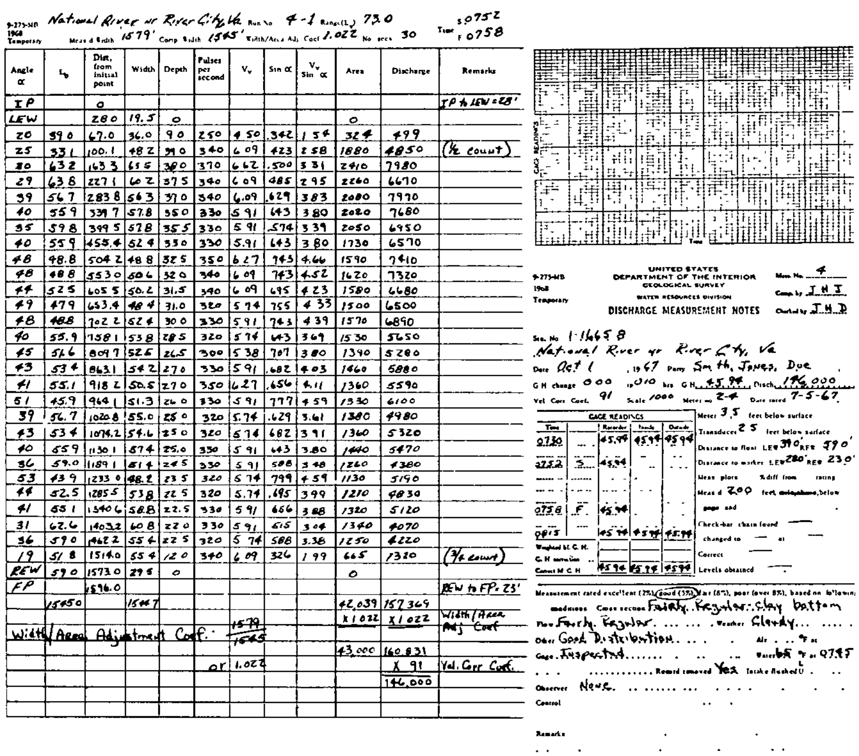


FIGURE 112.—Definition sketch of midsection method of computation superimposed on a facsimile of a sonic-sounder chart.

the end of a full count by the counter unit. In the sample measurement the value recorded was three-fourths of that in the table because the sounder chart distance between the last two vertical markings was approximately three-fourths of the normal spacing.

3. Each value recorded in column 3 represents the distance from the initial point (marker) to the observation point where the data were collected. The data in column 2, together with the "distance to float" and the "distance to marker" values recorded on the front sheet of the discharge measurement notes (fig. 113) are used to obtain these cumulative distances. For a moving-boat measurement, these distances are defined as follows:

b_1 = distance from initial point (marker) to edge of water
$b_2 = b_1$ + measured distance to float from edge of water
$b_3 = b_2 + L_{b_3}$
$b_4 = b_3 + L_{b_4}$



9-275-MD 1968 Temporary National River nr River City, Va. Run No. 4-1 Range(L) 73.0 Time S 0752 F 0758
Meas'd Width 1579' Comp Width 1545' Width/Area Adj Coef 1.022 No secs 30

Angle α	L_b	Dist. from initial point	Width	Depth	Pulses per second	V_v	Sin α	$\frac{V_v}{\text{Sin } \alpha}$	Area	Discharge	Remarks
IP		0									IP to LEW = 28'
LEW		28 0	19.5	0					0		
20	59 0	67.0	36.0	9 0	250	4 50	.342	1 54	324	499	
25	331	100.1	48 2	39 0	340	6 09	423	2 58	1880	4850	(½ count)
30	632	163 3	61 5	38 0	370	6 62	.500	3 31	2410	7980	
29	63 8	227 1	60 2	37 5	340	6 09	485	2 95	2260	6670	
39	56 7	283 8	56 3	37 0	340	6.09	.629	3 83	2080	7970	
40	55 9	339 7	57.8	35 0	330	5 91	643	3 80	2020	7680	
35	59 8	399 5	57 8	35 5	330	5 91	.574	3 39	2050	6950	
40	55 9	455.4	52 4	33 0	330	5.91	643	3 80	1730	6570	
48	48.8	504 2	48 8	32 5	350	6 27	743	4.66	1590	7410	
48	48 8	553 0	50 6	32 0	340	6 09	743	4.52	1620	7320	
44	52 5	605 5	50.2	31.5	340	6 09	695	4 23	1580	6680	
49	47 9	653.4	48 4	31.0	320	5 74	755	4 33	1500	6500	
48	48.8	702 2	52 4	30 0	330	5 91	743	4 39	1570	6890	
40	55.9	758 1	53 8	28 5	320	5 74	643	3 69	15 30	5650	
45	51.6	809 7	52.6	26.5	300	5 38	707	3 80	1390	5280	
43	53 4	863.1	54 2	27 0	330	5 91	.682	4 03	1460	5880	
41	55.1	918 2	50.5	27 0	350	6 27	.656	4.11	1360	5590	
51	45.9	964 1	51.3	26 0	330	5 91	777	4 59	1330	6100	
39	56.7	1020.8	55.0	25 0	320	5.74	.629	3.61	1380	4980	
43	53 4	1074.2	54.6	25 0	320	5 74	682	3 91	1360	5320	
40	55 9	1130 1	57 4	25.0	330	5 91	643	3.80	1440	5470	
36	59.0	1189 1	51 4	24 5	330	5 91	588	3 48	1260	4380	
53	43 9	1233 0	48.2	23 5	320	5 74	799	4 59	1130	5190	
44	52.5	1285 5	53 8	22 5	320	5.74	.695	3 99	1210	4830	
41	55 1	1340 6	58.8	22.5	330	5 91	656	3 88	1320	5120	
31	62.6	1403.2	60 8	22 0	330	5 91	515	3 04	1340	4070	
36	59 0	1462 2	55 4	22 5	320	5 74	588	3.38	1250	4220	
19	51 8	1514.0	55 4	12 0	340	6 09	326	1 99	665	1320	(¾ count)
REW	59 0	1573.0	29 5	0					0		
FP		1596.0									REW to FP = 23'
	1545 0		1544 7						42,039	157 369	
									x 1 022	x 1 022	Width/Area Adj Coef
Width/Area Adjustment Coef.						$\frac{1579}{1545}$					
									43,000	160 831	
					or	1.022				X 91	Vel. Corr Coef.
										146,000	

9-275-MB 1968 Temporary
UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION
DISCHARGE MEASUREMENT NOTES
Meas. No. 4
Comp. by J H J
Checked by J H D

Sta. No 1-1665 8
National River nr River City, Va
Date Oct 1, 1967 Party Smith, Jones, Doe
G H change 0 00 in 0 10 hrs G H 45.94 Disch 146,000
Vel Corr Coef. 91 Scale 1000 Meter no 2-4 Date rated 7-5-67

GAGE READINGS				
Time		Recorder	Inside	Outside
0730		45.94	45 94	45 94
0752	S	45.94		
0758	F	45.94		
0815		45 94	45 94	45.94
Weighted M. G. H.				
G. H correction				
Correct M. G. H.		45 94	45 94	45 94

Meter 3.5 feet below surface
Transducer 2 5 feet below surface
Distance to float LEW 39 0' REW 59 0'
Distance to marker LEW 28 0' REW 23 0'
Meas plots % diff from rating
Meas d 200 feet, below gage and
Check-bar chain found —
changed to — at —
Correct —
Levels obtained —

Measurement rated excellent (2%), good (5%), fair (8%), poor (over 8%), based on following conditions: Cross section Fairly Regular - clay bottom
Flow Fairly Regular Weather Cloudy
Other Good Distribution Air °F at
Gage Inspected Water 65 °F at 0745
Record removed Yes Intake flushed
Observer None
Control

Remarks

G.H. of zero flow

FIGURE 113.—Sample computation notes of a moving-boat measurement.

. . . .

$b_{(n-1)} = b_{(n-2)} + L_{b_{(n-1)}}$

$b_n = b_{(n-1)}$ + measured distance from float to edge of water

$b_{(n+1)} = b_n$ + distance to final point (marker).

4. Each of the incremental widths in column 4 represents the distance that extends laterally from half the distance from the preceding meter location $(x-1)$, to half the distance to the next, $(x+1)$. These values are obtained by using the distances in column 3.

5. Each of the values in column 5 represents the stream depth at a sampling point in the cross section. These values are obtained by adding the transducer depth to each of the depth readings recorded on the sounder chart at the sampling locations.

6. The data in column 6 are the pulses-per-second readings recorded by the notekeeper during the measurement.

7. The values recorded in column 7 represent the instantaneous velocity of the water past the vane at each observation point. They are read directly from the meter-rating table (fig. 108), using the pulses-per-second values of column 6.

8. The data in column 8 are the sine function values of the angle readings in column 1. These values may be obtained from the sine table in figure 108, using the angle readings of the first column.

9. Each of the values in column 9 represents the stream velocity normal to the cross section at that particular sampling point.. To obtain these values, it is necessary to multiply each V_V value in column 7 by the corresponding sin α value in column 8.

10. The values in column 10 represent the individual subsection areas for the measurement. They are obtained by multiplying the widths of column 4 by their corresponding depths in column 5. The incremental areas are then summed to provide the total unadjusted area for the measurement.

11. Each quantity in column 11 represents the unadjusted discharge through one of the subsections of the discharge measurement. These values are summed to provide the total unadjusted discharge of the measurement.

12. This column is used for recording any descriptive remarks pertaining to the measurement.

ADJUSTMENT OF TOTAL WIDTH AND AREA

As explained on page 186, the relation expressed by the equation $L_b \approx L_V \cos\alpha$ is used to obtain the incremental widths across the stream. This equation is based on the assumption that a right-triangle relationship exists among the velocity vectors involved. If the flow is not normal to the cross section, that assumed situation does not exist and the use of the equation can result in a computed width that is too large or too small (fig. 114), depending on whether the vector quantity representing the oblique flow has a horizontal component that is opposed to, or in the direction of, that of the boat path. Thus in figure 114 the computed width would be AB' of the right triangle $AB'C$ rather than the true width AB of oblique triangle ABC. In this case the computed width is too large, whereas the computed width DE' of right triangle $DE'F$ is less than the actual width DE of oblique triangle DEF.

Ideally the correction for error in the computed width would be applied to that particular increment in the cross section where the error occurred. However, in practice only the overall width is directly measured, and thus only the total width is available for comparison with the computed quantities. Therefore, if the sum of the computed incremental widths does not equal the total measured width of the cross section, it is assumed that each increment requires a proportionate adjustment.

The moving-boat method uses the relation between the measured and computed widths of the cross section to determine a width/area adjustment factor. To obtain that coefficient, the measured width of the cross section is divided by its computed width, that is

$$k_B = \frac{B_m}{B_c} \qquad (22)$$

where

k_B = width/area adjustment factor,
B_m = measured width of cross section, and
B_c = computed width of cross section.

The coefficient (k_B) is then used to adjust both total area and total discharge of the measurement, on the basis of the previously mentioned assumption that the error in width is evenly distributed, on a percentage basis, across each width increment of the cross section.

The computation notes in figure 113 provide an example of the application of a width/area adjustment coefficient.

ADJUSTMENT OF MEAN VELOCITY AND TOTAL DISCHARGE

During a moving-boat discharge measurement, the current meter is set at a predetermined fixed depth of from 3 to 4 ft (0.9 to 1.2 m) below the water surface. In other words, this technique uses the subsurface method of measuring velocity. (See page 136.) The measurement is computed by using constant-depth subsurface velocity observations without adjustment coefficients, as though each observed velocity were a mean in the vertical. In adjusting the computed discharge, each measured velocity should ideally be multiplied by a coefficient to adjust it to the mean velocity in its vertical. However, it

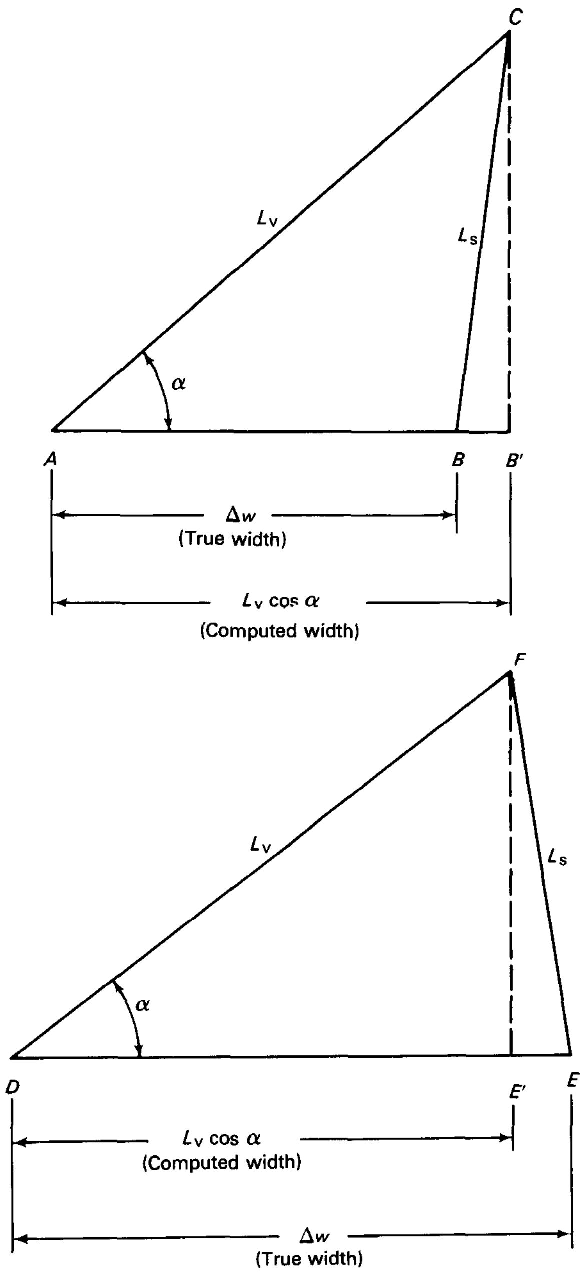


FIGURE 114.—Comparison of actual and computed values of incremental widths.

is assumed that in the larger streams where the moving-boat technique would be applicable, these coefficients would be fairly uniform across a section, thus permitting the application of an average velocity coefficient to the total discharge. Information obtained from several vertical-veolocity curves, well distributed across the measurement section, would be needed to determine a representative velocity coefficient for the total cross section.

DETERMINATION OF VERTICAL-VELOCITY ADJUSTMENT FACTOR

Vertical-velocity curves (p. 132–133) are constructed by plotting observed velocities against depth. The vertical-velocity curve method calls for a series of velocity observations (by conventional methods) at points well distributed between the water surface and the streambed. Normally these points are chosen at 0.1-depth increments between 0.1 and 0.9 of the depth. Observation should also be made at least 0.5 ft (0.15 m) from the water surface and 0.5 ft (0.15 m) from the streambed; for this particular application, a velocity reading should be made at the moving-boat sampling depth of from 3 to 4 ft (0.9 to 1.2 m) below the water surface. Once the velocity curve has been constructed, the mean velocity for the vertical can be obtained by measuring the area between the curve and the ordinate axis with a planimeter, or by other means, and then dividing this area by the length of the ordinate axis.

To obtain a velocity-correction coefficient at location x in the cross section, the mean velocity in the vertical is divided by the observed velocity at the measured depth, that is,

$$k_V = \frac{\overline{V}}{V}\ , \tag{23}$$

where

k_V = vertical-velocity adjustment factor,
$\overline{V}$ = mean velocity in the vertical, and
V = observed velocity (3- or 4-ft depth).

To arrive at a representative average coefficient, coefficients should be determined at several strategically located verticals that are representative of the main portion of the streamflow. Once an average coefficient has been determined, it should not be necessary to redetermine it each time when making future discharge measurements at the same site. However, it would be necessary to test its validity at several widely varying stages and, in estuaries, at widely different parts of the tidal cycle.

Investigations on the Mississippi River at both Vicksburg and St. Louis, on the Hudson River at Poughkeepsie, and on the Delaware

River at Delaware Memorial Bridge all indicated coefficients that lie in the narrow range of 0.90 to 0.92 for adjusting the subsurface velocity to the mean velocity. Carter and Anderson (1963) present a table of velocity ratios and standard deviations for various relative depths. That table indicates that for depths of 10 ft (3 m) or more, an average coefficient of 0.90 is satisfactory for adjusting velocities obtained 4 ft (1.2 m) below the surface to mean velocity. The sample from which the data in that table were obtained consisted of 100 stream sites at each of which 25 to 30 verticals had been used. Similar conclusions concerning subsurface velocity coefficients can be drawn from table 2 (p. 132).

APPLICATION OF VELOCITY ADJUSTMENT TO COMPUTED DISCHARGE

Application of the vertical-velocity adjustment factor is made immediately after the width-area adjustment has been applied to the computed discharge. In other words, after the computed discharge has been multiplied by the width-area adjustment factor, the resulting product is multiplied by the vertical-velocity adjustment factor. The final product is the adjusted, or "true," discharge for the measurement. (See fig. 113.)

SELECTED REFERENCES

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